FORM PTO-1390 (REV 11-98) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER: BEET-03

U.S. APPLICATION NO. (If known, see 37 CFR 1.5): 09/806410

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/EP98/06225	September 30, 1998	September 30, 1998

TITLE OF INVENTION: Depth Measurement and Depth Control Or Automatic Depth Control For A Hollow To Be Produced By A Laser Processing Device

APPLICANT(S) FOR DO/EO/US: Michael Kuhl et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. [X] This is a FIRST submission of items concerning a filing under 35 U.S.C. 371.
2. [ ] This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 U.S.C. 371.
3. [X] This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. [X] A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. [X] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. [X] is transmitted herewith (required only if not transmitted by the International Bureau).
   b. [X] has been transmitted by the International Bureau.
   c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US).
6. [X] A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. [ ] Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. [ ] are transmitted herewith (required only if not transmitted by the International Bureau).
   b. [ ] have been transmitted by the International Bureau.
   c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
   d. [ ] have not been made and will not be made.
8. [ ] A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. [X] An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. [X] A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern document(s) or information included:

11. [X] An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. [ ] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. [X] A FIRST preliminary amendment.
    [ ] A SECOND or SUBSEQUENT preliminary amendment.
14. [ ] A substitute specification.
15. [ ] A change of power of attorney and/or address letter.
16. [X] Other items or information:

--Copy of Form PCT/IB/308 International Application to the Designated Offices
--Copy of Front Page of Published Application WO 00 19167
--Copy of Form PCT/ISA/220 International Search Report with Three (3) References
--Copy of Form PCT/IPEA/416 With Annexes and Translation of Annexes
--Copy of Submission of March 6, 2001 to WIPO
--Formblatt PCT/RO/101
--Express Mail Cert. No. EL725699477US
--Return Postcard

SCANNED, # 2

JC03 Rec'd PCT/PTO 30 MAR 2001

U.S. APPLICATION NO. (if known, see 37 CFR 1.5)	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
09/806410	PCT/EP98/06225	BEET-03

17. [X] The following fees are submitted:

	CALCULATIONS	PTO USE ONLY
BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):		
Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO $1,000		
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO 860		
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO 710		
International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) 690		
International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) 100		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 860.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	26 - 20 =	6	X $18.00	$ 108.00	
Independent claims	4 - 3 =	1	X $80	$ 80.00	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ $270	$	
TOTAL OF ABOVE CALCULATIONS =				$1,048.00	
Reduction of 1/2 for filing by small entity, if applicable. A Small Entity Statement must also by filed (Note 37 CFR 1.9, 1.27, 1.28).				$	
SUBTOTAL =				$1,048.00	
Processing fee of **$130.00** for furnishing the English translation later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$	
TOTAL NATIONAL FEE =				$1,048.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +				$	
TOTAL FEES ENCLOSED =				$1,048.00	
				Amount to be: refunded	$
				charged	$

a. [X] A check in the amount of $1,048.00 to cover the above fees is enclosed.

b. [ ] Please charge my Deposit Account No. ______________ in the amount of $______________ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. [X] The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 23-3000. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO

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PCT INITIAL PROCESSING
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SIGNATURE

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40,532
REGISTRATION NUMBER

09/806410

JC03 Rec'd PCT/PTO 30 MAR 2001

Express Mail No. EL725699477US
PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Serial No.:	Unknown (National Phase of International Application PCT/EP98/06225; filed September 30, 1998)
Filed:	March 29, 2001
Applicant:	Michael Kuhl et al.
Title:	**DEPTH MEASUREMENT AND DEPTH CONTROL OR AUTOMATIC DEPTH CONTROL FOR A HOLLOW TO BE PRODUCED BY A LASER PROCESSING DEVICE**
Our Ref:	BEET-03

Cincinnati, Ohio 45202 March 29, 2001

PRELIMINARY AMENDMENT

Sir:

Prior to examination of the above-identified application, please amend the application as follows:

In the Claims:

Please cancel claims 1-26 without prejudice or disclaimer.

Please add new claims 27-52 as follows:

27. (NEW) Method for making a specifically formed hollow in a work piece by means of a laser machining apparatus which, in a layer-wise manner, removes material from the work piece in horizontal layers (S; xy) corresponding to the specific shape, wherein the depth (z) of the hollow is continuously measured, characterized in that

the boundaries (x_g, y_g,) in horizontal direction for removal in a subsequent layer (S_{i+1}) are determined in accordance with the depth (z) of the hollow from the form definition of the hollow.

28. (NEW) Method according to claim 27, characterized in that the thickness (Δz) of a removed layer (S_i) is determined from measured depths of the hollow, and the boundaries (x_g, y_g) in horizontal direction for removal in a subsequent layer (S_{i+1}) is determined also in accordance with the determined layer thickness (Δz) from the form definition of the hollow.

29. (NEW) Method according to claim 27, wherein the boundaries of removal in a layer are determined with reference to stored form data of the hollow.

30. (NEW) Method for forming a specifically formed hollow in a work piece by means of a laser machining apparatus which removes, in a layer-wise manner, material of the work piece in accordance with the defined shape, the depth of the hollow being continuously measured,

characterized in that the measured values are continuously stored together with the respective coordinates or at memory locations corresponding to the respective coordinates and are later on used for driving the laser machining apparatus.

31. (NEW) Method according to claim 30, characterized in that a stored measured value is used when, within the same layer, the laser is near a site corresponding to the measured valued and/or when, in a subsequent layer, the laser is at or close by a site corresponding to the measured value.

32. (NEW) Method according to claim 30, characterized in that a measurement value is used for adjusting the instantaneous or future interaction parameters of a laser beam.

33. (NEW) Method according to claim 32, characterized in that for a pulsed laser the laser amplitude and/or the impulse elevation and/or the duty ratio are adjusted.

34. (NEW) Method according to claim 30, characterized in that the stored measured values are used for removing a partial layer.

35. (NEW) Method according to claim 30, in which for measuring the depth with a depth sensor a light emanating from a working site is used,

characterized in that the depth sensor is calibrated,

a depth is measured at a specific site of the hollow,

the measured value is corrected in accordance with the position of the site and with reference to the correction values stored during calibration, and the corrected value is used as measured depth.

36. (NEW) Method according to claim 35, characterized in that correction is made by adding a value or by multiplying a value.

37. (NEW) Method according to claim 35, characterized in that a correction is made in accordance with the depth of the hollow.

38. (NEW) Method according to one of the claims 35, wherein for calibrating the depth sensor the depth of measurement points on a calibrating surface with known shape are measured,

the measured values are compared with known values at the respective measurement point of the calibrating surface, and

correction values are stored in accordance with a difference between the measured value and the known value together with the respective coordinates or at memory locations corresponding to the respective coordinates.

39. (NEW) Method according to claim 38, characterized in that for depth measurement the sensor uses a light emanating from the working site, and that laser light is guided through a laser beam guidance across the surface of the work piece within a working area defined by the apparatus.

40. (NEW) Method according to claim 38, characterized in that the calibrating surface is a plane.

41. (NEW) Method according to claim 40, characterized in that the calibrating surface is measured a plurality of times, and the calibrating surface is shifted as compared to the measurement system in horizontal direction between various measurements, wherein for measurement points corresponding to each other within the working area or being close to each other correction values are formed in accordance with all measurements for said measurement point and are stored for said measurement point.

42. (NEW) Method according to one of the claims 38, characterized in that the distance between measurement points in advancing direction of the laser beam is determined by the processing speed of a digital system and by the advancing speed of the laser beam.

43. (NEW) Method according to claim 40, characterized in that the calibrating surface has an unevenness smaller than 5 micrometers, preferably smaller than one micrometer.

44. (NEW) Apparatus for making a specific shaped hollow (10) in a work piece (11), comprising

a laser machining apparatus (12-18) which, in a layer-wise manner, removes material of a work piece (11) in horizontal layers (S; xy) corresponding to the specific shape, and

a measurement apparatus (70-73) which continuously measures the depth (z) of the hollow,

characterized by a control apparatus (81) which determines the boundaries (x_g, y_g) in horizontal direction for removal in a subsequent layer (S_{i+1}) in accordance with the depth (z) of the hollow from the form definition.

45. (NEW) Apparatus according to claim 44, characterized in that the control apparatus comprises a determining meands (82) for determining the thickness (Δz) of a removed layer (S_i) from the measured depth of the hollow, and the control apparatus (81) determines the boundaries (x_g, y_g) in horizontal direction for removal in a subsequent layer (S_{i+1}) also in accordance with the determined layer thickness (Δz).

46. (NEW) Apparatus according to claim 44, characterized by a memory (83) for storing the form definition of the hollow (10).

47. (NEW) Apparatus for making a specifically shaped hollow (10) in a work piece (11), comprising

a laser machining apparatus (12-18), which, in a layer-wise manner removes material from the work piece (11) corresponding to the specific shape, and a measurement apparatus which continuously measures the depth (z) of the hollow,

characterized by a memory means (91) which continuously stores the measurement values together with the respective coordinates or at memory locations corresponding to the respective coordinates, and

a control apparatus (63, 92, 93) which controls the laser machining apparatus (12-18) in accordance with the stored measurement values.

48. (NEW) Apparatus according to claim 47, characterized in that the control apparatus uses a stored measurement value if within the same layer the laser beam is close by a site corresponding to said measurement value, and/or if, in a deeper layer, the laser is close by or at a site corresponding to the measurement value.

49. (NEW) Apparatus according to claim 47, characterized in that the control apparatus uses a measurement value for the instantaneous or later adjustment of the interaction parameters of the laser beam.

50. (NEW) Apparatus according to claim 44, the laser machining apparatus (12-18) guiding, by means of a laser beam guidance, the laser light across the surface of a work piece within a working area defined by the apparatus, comprising

a depth sensor (70, 71) which uses for depth measurement light emanating from the working site and generates a measurement value,

characterized by a calibrating apparatus (72-74) adapted to measure a preferably flat calibrating surface and having a memory (73) for storing correction values in accordance with differences between measurement values and known

values together with the respective coordinates or at memory locations corresponding to the respective coordinates, and

a correction apparatus (74, 75) which corrects the measurement value in accordance with the position of the site with reference to the correction values stored in said memory (74).

51. (NEW) Apparatus according to claim 50, characterized in that the correction is made by adding a value and/or by multiplying a value.

52. (NEW) Apparatus according to claim 50, characterized in that a correction is made in accordance with the depth of the hollow.

REMARKS

Applicants have canceled claims 1-26 without prejudice or disclaimer. Please add new claims 27-52.

Attached hereto is a marked-up version of the changes made to the claims by the current amendment. The attached page is captioned **"Version with markings to show changes made"**.

Respectfully submitted,

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VERSION WITH MARKINGS TO SHOW CHANGES MADE

In the Claims:

Claims 1-26 have been canceled.

Claims 27-52 have been added.

09/806410
JC03 Rec'd PCT/PTO 30 MAR 2001

DEPTH MEASUREMENT AND DEPTH CONTROL OR AUTOMATIC DEPTH CONTROL FOR A HOLLOW TO BE PRODUCED BY A LASER PROCESSING DEVICE

The invention, in the most general sense, relates to the depth measurement and the depth control or automatic depth control of a hollow to be produced by al laser processing device.

A depth measuring system is known from the DE OS 42 06 499. In this case an incoherent process light is analysed, for example by a triangulation method or by analysing the distance between different reflections of the light spot.

For representing the light spot on a sensor or a sensor array a lens is required. Since the light spot may be disposed on any position in the working area Bx, By, it has to be taken care that focusing is sufficiently accurate in all positions of the light spot in the working area of the laser processing device.

Conventional lenses have a spherical focal surface. Since the surface currently worked by the laser processing device, however, is generally not spherical, a slight defocusing will therefore always occur. So-called Fθ-lenses are corrected so that they have a flat focal surface. However, this focal surface also is not completely plane so that defocusing may occur. Depending on the desired measuring accuracy such lack of definition may lead to an unacceptable loss of accuracy. The mentioned Fθ-lenses enable measuring accuracies in the range of about 100 μm. The inaccuracy of the focal plane of said Fθ-lenses is also in this range. In modern laser processing devices, however, production accuracies of a few micrometers are obtainable or controllable. Then, however, correspondingly accurate measuring systems are also required which, in particular, should be about as accurate as the production accuracy. The required accuracies can not be obtained with the measuring system known from the DE 42 06 499. This is particularly true when the measuring system

is integrated in the processing system, and especially when both use the same optics. The process light used for the measurement then passes through a comparably wide section of the imaging system so that the mentioned inaccuracies will clearly occur. They may be in the range of tenths of millimetres.

From the DE 42 09 933 a method for partially changing the surfaces of metallic and non-metallic bodies with an Nd:YAG-laser is known. A substance removal in the depth direction is not described therein.

The formation of hollows by means of laser processing devices has so far been effected by carrying out a layer-wise removal of substance. The layer thickness is respectively predetermined and will be controlled. This results in the drawback that performance reserves need to be provided to ensure that the target control can safely be obtained in any case. In addition, known methods have the disadvantage that for a depth control the success of the control is effected in another position than the measuring position. This is due to the processing speed of the controller and the guiding speed of the laser beam. During the processing period the laser beam is moved ahead so that the control result occurs locally displaced. This tends to apply also to further layers so that difficulties concerning the depth control may occur.

It is the object of the invention to provide a method and an apparatus for an exact depth measurement and for an accurate depth control in laser processing devices.

Said object is solved by the features of the independent claims. Dependent claims are related to preferred embodiments of the invention.

An exact depth measurement can be obtained by calibrating the actual sensor system particularly for the optics used. To this end a known calibration surface, preferably a plane, is measured. The actual values will then be compared with the known values, and correction values for the respective position in the working area will be generated and stored in accordance with the difference.

In the present description it is assumed that the depth of the hollow extends in the z-direction of a rectangular coordinate system while the working area is a plane extending substantially in the x-y-plane of the coordinate system (see Fig. 1). For the working area Bx, By thus a two dimensional correction field is determined which may then be used for the correction of the actual measurements.

Instead of working with fixed layer thicknesses like in the case of the state of the art, it is also possible to determine the current depth z of the hollow and to

determine the boundaries in the x- and y-directions for a following, particularly the next layer to be removed, from the definition of the shape to be produced depending on said absolute hollow depth. In the case of a form converging in tub-shape towards the bottom it might, for example, be found that during the removal of one layer the material was penetrated deeper than intended. In the next layer then narrower boundaries would be set in the x- and y-directions.

A further enhancement of the accuracy will be obtained when not only the absolute depth of the hollow is taken into consideration in calculating the boundaries in the horizontal direction for the next layer but also the layer thickness currently removed with the currently used parameters. With said layer thickness Δz a more accurate progress in the z-direction of the shape definition is achievable so that, correspondingly, more accurate boundaries may be calculated for the next layer.

To obtain "a priori" information for the control of the apparatus the continuously determined depth measurement values may be stored, particularly in accordance with their x- and y-coordinate values. The so stored information may be used in the further progress to take appropriate measures.

It is to be explicitly noted here that the applicant has filed two other patent applications relating to methods and apparatuses for processing a workpiece with a laser at a date very close to the application day of the present patent application, namely the applications no. ... ("Patching") and no. ... ("Trennmittel"). Herein and if required below in the following text said applications are explicitly referred to.

Below individual embodiments of the invention are described with reference to the appended drawings in which:

Fig. 1 is a schematic view of a laser processing device;

Fig. 2 is a schematic functional block diagram of a controller;

Fig. 3 shows the depth measuring device of Fig. 2;

Fig. 4 shows the control unit of Fig. 2 for determining the substance removal boundaries in one layer;

Fig. 5 shows the control unit of Fig. 2 for storing measured values; and

Figs. 6 and 7 are a plan view and a cross sectional view schematically showing a workpiece for discussing general considerations.

Fig. 1 is a schematic view of a laser processing device. If required the description will be given with reference to the mentioned rectangular x-y-z-coordinate system, x and z being shown in the plane of the drawing and y extending downwards through the plane of the drawing.

A column 16 carries a working head 13 and a workpiece table 14 which is shiftable if required. In general a relative movement between the head 13 and the workpiece 11 is possible at least in the x-y-plane. This is indicated by rollers 15 between the workpiece table 14 and the foot 16. Instead or in addition the head 13 may also be movable. In the workpiece 11 a hollow 10 is formed. The hollow is generated by means of a laser beam 12. As a rule, a layer-wise removal of substance is carried out by successively removing layers respectively located in different positions in the z-direction and extending in the x-y-plane from the top to the bottom. In Fig. 6 this is schematically shown: In the upper part of the cross sectional view a line 107 shows the desired final shape together with the visible contours. Said final shape is generated by a layer-wise removal of substance. The layers are indicated in the illustration 106. The broken lines show layers already removed while the continuous lines indicate layers yet to be processed. The currently processed layer is denoted by S_i, the previous layer by S_{i-1}, the following layers by S_{i+1}. Combinations of the mentioned possibilities are also possible.

For removing a layer different strategies are feasible: Within the working area Bx, By of the head the laser beam is guided across the surface by a suitable laser beam guidance. Meandering embodiments are shown. In the upper part of the plan view an embodiment is shown in which the beam guidance principally scans the whole working area Bx, By, the laser beam being turned on only when it scans a surface to be processed, i.e. the bottom of the hollow 10. That corresponds to the continuous lines 101b, while the broken lines 101a indicate the "dark path". In the lower part of the plan view, on the other hand, an embodiment is shown in which the laser beam guidance guides the laser only across the surfaces to be processed, i.e. across the current bottom of the hollow. When a layer S_i is removed, the process is continued with the removal of the next layer S_{i+1}.

The working area Bx, By is generally limited by constructional conditions. In general rectangular areas are concerned outside of which the laser beam can no longer be guided. In the lower part of Fig. 1 this is schematically shown. Here the working head is assumed to be a spot light source 13. The deflection of the beam may be effected between a farthest possible left position 12a and a farthest possible

right position 12b. Therewith an area Bx in the x-direction is obtained. The same applies analogously to the y-coordinate.

The apparatus of Fig. 1 is provided with a controller 17 which is connected to the processing device via lines 18. The control unit 17 (which will simply be referred to as controller below) may be compact or formed spatially distributed. It will generally comprise digital components, for example a process computer.

Fig. 2 schematically shows a functional block diagram of the construction of the controller 17. N signal input lines 18a and m signal output lines 18b are provided. They pass driver/coupling/converter/ processing components 67a, 67b which carry out conversions related to data formats, performance and the likes. The controller 17 comprises at least one memory 64 in which different kinds of data can be stored. In addition, different general control or automatic control functions 65 are provided (for example for laser scanning, laser beam guidance, etc.). 68 denotes functions corresponding to the functions and features described in the two other patent applications ("Patching" and "Trennmittel") mentioned above. They may be provided together with the functions according to the invention and may have advantageous effects. 66 denotes a channel enabling the required communication between the individual ones. As far as it is to be regarded as hardware it may, for example, be a bus of a computer.

61 denotes the function of a depth measurement according to the invention, 62 denotes a control function for determining the processing boundaries in a layer S_i according to the invention, and 63 denotes a function for storing and later analysing the measured values according to the invention. The functions 61 - 63 operate with at least the memory 64 and with other functions depending on the requirements. They may also interact with the functions 68 described in the two other applications.

Fig. 3 shows an exemplary embodiment of a depth measuring device. Numerals corresponding to the ones used in the previous drawings denote identical components. An embodiment is shown in which the primary sensor 70 is spatially integrated with the working head 13 (for emitting the processing laser beam). In particular the process light analysed by the sensor 70 at least partially passes the same optics as the working laser beam. A line sensor is shown which receives an image of the light spot on the working position on the workpiece 11 just illuminated by the laser beam. The measuring principle of the sensor may be as described in the DE OS 42 06 499. The sensor outputs a more or less widely spread signal which is received by the controller 17 and particularly by the depth measuring unit 61 ac-

cording to the invention. 71 denotes a complex signal processing unit which transforms a comparably crude sensor signal into a depth value z (along the z-coordinate in Fig. 1).

To obtain an exact measurement the depth measuring device is calibrated previous to the actual depth measurement. To this end a calibrating surface is measured. The calibrating surface has a known shape which is preferably flat. Preferably the calibrating surface is so large that the whole working area Bx, By can be accommodated on it. In one calibrating pass the height of the calibrating surface in the z-direction is measured on different points (distributed, for example, in a grid shape) in the working area Bx, By. The so obtained measured value will be compared with the known height of the calibrating surface (denoted by 72) in a comparator 73. The difference provides a scale for the measuring error. The difference may be stored in the memory 74 depending on the position or may be used for determining a correction value to be stored depending on the position as well. "Depending on the position" in this connection means depending on the position in the x- or y-directions within the working area Bx, By. The x- and y-coordinates are known to the controller 17 from the general functions 65.

During the calibrating process thus a plane correction field is stored which may than be used for correcting the actually measured values. This is symbolised by a component 75. It receives an actually measured value via the sensor 70, lines 18, 66 and a signal former 71. In addition, it receives a correction value corresponding to the depth measurement position in its position from the memory 74. In the correction device 75 the measured value is corrected and output or held for other system functions. The correction may be carried out by addition and/or by multiplication. An identification field may also be provided. A correction depending on the absolute depth z may also be provided.

During the calibration process the calibration surface may be measured a plurality of times while being shifted in the horizontal direction (x and/or y) between the individual measurements. In this case correction values depending on the measured values obtained for the respective position x, y in the working area Bx, By will be determined for the individual positions in the working area Bx, By (by averaging, interpolation or the likes). For the correction of actually measured values also interpolations or averaging can be carried out, particularly when no or only a remotely located correction value exists for the current measuring position.

The calibration according to the invention or the depth measurement according to the invention enable a measuring accuracy in the range of a few micrometers, preferably below 1 μm. The correction values may, as far they are correction values obtained by addition, correspond to a value of up to 1 mm or more.

The depth measurement in the z-direction described above may but need not be used in the functions described below.

Fig. 4 schematically shows a controller for the layer removal. The basic considerations will be explained with reference to Fig. 7. Identical numerals therein denote features corresponding to the ones in the previous figures. Fig. 7 shows the laser beam 7 impinging on the bottom 112 of the hollow 10. A moving direction of the laser beam 12 in the direction of the arrow 111 (i.e. in the x-direction in this case) effected by the laser beam guidance is assumed. The material of the layer Si is vaporised and liquefied and thus removed. This is indicated by the arrows directed away from the working position 110. The thickness of a layer is assumed to be Δz, the measured absolute depth is z. The wall 113 of the hollow 10 is to follow the contour 107 in the lower layers as well. The boundary x_g for the removal in the following layer S_{i+1} therefore depends on the depth z particularly in the case of inclined walls, a d_z will lead to a dx_g. As long as it is possible to set the depth z to predetermined values from layer to layer the boundaries for the layer removal in a layer x_g (and correspondingly y_g) can also be previously set and then adjusted. That corresponds to a fixed programming of the device. It may, however, be desirable not to insist in said layer thicknesses. Sometimes it may also be technically impossible. It will then be advantageous to determine the removal boundaries in the x-y-plane for the next layer S_{i+1} based on the actual depth z since a change of z will also result in a change of x_g and y_g. This corresponds to a flexible programming. A device for realising that consideration is schematically shown in Fig. 4. It comprises a control device 81 for determining the horizontal boundaries x_g, y_g for the substance removal in a following layer, particularly S_{i+1}, from the shape definition stored in a memory 83 depending of the depth z of the hollow. To this end, on the one hand, the control unit 81 receives data containing the shape definition, and, on the other hand, the depth z (or a value derived from it, for example, filtered or averaged). From said data the boundaries x_g, y_g in the horizontal direction for the layer removal may be determined and supplied to the conventional components 65 for adjusting said values.

A further increase of the accuracy will be obtained when not only the absolute depth z but also the layer thickness Δz just removed with the current parameters

is considered for determining the substance removal boundaries x_g, y_g. The calculation "into the depth of the hollow" does then not need to be carried out using a theoretical value for the layer thickness, but the currently actually removed layer thickness may be used.

When only the measured depth z (together with a theoretical value for the layer thickness) is taken into consideration for the boundary determination, the generation of a cumulative error is avoided and at most a non-cumulative error corresponding to the difference between the theoretical and the actual layer thickness occurs which may be tolerable in some cases. When the actual layer thickness Δz is also considered in the determination of the boundaries the occurance of said residual error will also be prevented.

Fig. 4 shows means 82 for determining the layer thickness. It may, for example, be designed so that it will remember measured values z of the previous layer S_{i-1} and then compare these with the values measured during the removal of the layer S_i. The difference corresponds to the layer thickness Δz. In this case also filtered or averaged values may be used.

The definition of the shape of the hollow may, for example, be stored in the memory 83 in the form of CAD-data. The device 81 is possibly a relatively complex structure which can calculate intersection edges between a plane (corresponding to a value of $z + \Delta z$) and a shape (corresponding to the shape definition of the hollow) from the kind of data stored in the memory 83.

Fig. 5 shows a function for continuously storing the continuously measured depth data z. The storage is preferably carried out in memory locations corresponding to the position of the measured location in the working area of the device. It is not always possible to produce the current bottom 112 so evenly as shown in Fir. 7. Rather, waviness or plateaux or indentations may occur. In Fig. 6 the numeral 103 denotes a plateau. Under consideration the movement of the laser beam 12 in Fig. 7 in the direction of the arrow 111 a feeding speed v_x may be determined. If, on the other hand, it is assumed that the reaction speed of the system is limited to one measurement, a time t_R can be determined as a reaction period which will pass until a measured value of z can have an effect on the laser 12. Due to the reaction time t_R and the feeding speed v_x control interventions will principally become effective with a spatial offset. That corresponds to a dead time under a control technical aspect. In disadvantageous cases oscillations (waviness) may occur. The offset corresponds to $\Delta x = v_x \cdot t_R$ and is therefore absolutely included in the range of the ob-

served accuracies (e.g. $v_X = 01$ m/s, $t_R = 0{,}5$ ms, $\Delta x = 50$ μm). To compensate such disadvantageous effects it may be desirable to store measured values for the depth z and to take them into consideration later. This may lead to control overlapping or underlying the automatic control depending on the stored depth data.

When the depth z is measured continuously or quasi-continuously it may also be continuously written into a memory 91 and used in a suitable manner later. A topography or topographic mapping of the current hollow bottom will then be generated in the memory 91, said mapping being a tabular reflection of the respectively measured depth values z. The density of the measuring points on the surface towards high values is limited in the feeding direction of the laser beam by the feeding speed v_X and the reaction time t_R and can be selected below said limits. In the case of a meandering surface coverage according to Fig. 7 the density of the measuring points is determined by the track distance of the meanders in the direction transverse to the feeding direction.

When the topographical mapping or the topography indicates, for example, a plateau 103, this a priori information may be used for levelling out said irregularity without the temporary offset due to the reaction time of the system preventing the error correction. Owing to the a priory information the interaction parameters of the laser can be changed (towards a stronger substance removal in the case of plateaux, towards a weaker substance removal in the case of indentations) in the range of a recognised irregularity, or additional layers for removing only the irregularity (the plateau or the land around the indentation) may be inserted in the case of larger deviations.

A change of the interaction parameters of the laser beam may be effected when the laser beam passes the vicinity of the error again within the same layer (for example in the neighbouring track in the case of a meandering guidance according to Fig. 6). It is assumed here that the effect of the laser beam can not be accurately limited to one track. The effective area is rather indistinctly limited so that the laser beam incident on the current hollow bottom will not only be effective in the "ideal", currently observed track but also in the adjacent tracks. In addition the interaction parameters of the laser beam may also be changed in the following layers, for example in the next lower layer, to level out an irregularity recognised in an earlier layer.

With the described adjustment of the interaction parameters depending on the stored hollow depth data as a control the control of the laser depending on the

currently measured values may be maintained. The laser, however, may also be operated depending on the currently measured values without said control so that it is controlled only depending on the stored parameters.

The topographic mapping described may advantageously be combined with the determination of the substance removal boundaries in the horizontal direction described with reference to Fig. 4. Said techniques may be used in connection with the described measuring arrangement (referencing a calibrating curve) individually or in combination. The topographic mapping method described with reference to Fig. 5 can also be used together with the method for adjusting the relative position described in the other application no. ... ("Patching") of the applicant. For example, the relative positions of the working head and the workpiece may be selected so that critical areas on the workpiece (for example a plateau 103 or an indentation) will not come to be located in the boundary sections of the working area of the device so that a reliable processing of the corresponding position will become possible. An influence on the separation means supply in accordance with the application no. ... ("Trennmittel") depending on the data stored during the topographic mapping is also possible.

CLAIMS

1. Method for calibrating a depth sensor of a laser processing device by which a hollow can be formed in the surface of a workpiece,

characterised in that

the depths of the measuring points are measured on a calibration surface of known shape,

the measured values are compared with known values at the respective measuring points of the calibration surface, and

correction values depending on differences between the measured values and the known values are stored together with the respective coordinates or at memory locations corresponding to the respective coordinates.

2. Method according to claim 1, characterised in that the depth sensor uses light emitted from the working position for measuring the depth and the laser light is guided across the surface of the workpiece within a working area predetermined by the device with the aid of a laser beam guidance.

3. Method according to claim 1 or 2, characterised in that the calibration surface is a plane.

4. Method according to claim 3, characterised in that the calibration plane is measured a plurality of times while being displaced in the horizontal direction with respect to the measuring system between the individual measurements, correction values for measuring points corresponding to each other or being located close to each other in the working area being generated depending on all measurements for that measuring point and stored for that measuring point.

5. Method according to one of the preceding claims, characterised in that the distance between measuring points in the feeding direction of the laser

beam is determined by the processing speed of a digital system and by the feeding speed of the laser beam.

6. Method according to claim 3, characterised in that the calibration plane has a waviness of less than 5 µm, preferably less than 1 µm.

7. Method for a depth measurement in a hollow produced by a laser processing device by means of a depth sensor using light emitted from the working position for measuring the depth, the laser light being guided across the surface of the workpiece within a working area predetermined by the device with the aid of a laser beam guidance,

   characterised in that

   the depth sensor is calibrated by a method according to one of the claims 1 to 6,

   a depth is measured at a certain location in the hollow,

   the measured value is corrected depending on the position of the location and referring to the stored correction values, and

   the corrected value is used as the measured depth.

8. Method according to claim 7, characterised in that the correction is effected by addition and/or multiplication.

9. Method according to claim 7 or 8, characterised in that a correction is effected depending on the depth of the hollow.

10. Method for producing hollow of defined shape in a workpiece using a laser processing device for the layer-wise removal of the material of the workpiece in horizontal layers (S; x, y) in correspondence with the defined shape, the depth (z) of the hollow being continuously measured, particularly according to one of the claims 7 to 9,

    characterised in that

the boundaries (x_g, y_g) in the horizontal direction for the substance removal in a following layer (S_{i+1}) are determined from the shape definition of the hollow and depending on the depth (z) of the hollow.

11. Method according to claim 10, characterised in that the thickness (Δz) of a removed layer (S_i) is obtained from measured hollow depths and the boundaries (x_g, y_g) in the horizontal direction for the substance removal in a following layer (S_{i+1}) are also obtained from the shape definition of the hollow and depending on the determined layer thickness (Δz).

12. Method according to claim 10 or 11, characterised in that the determination of the substance removal boundaries of one layer is carried out with reference to stored shape data of the hollow.

13. Method for producing a hollow of defined shape in a workpiece using a laser processing device for the layer-wise removal of the material of the workpiece in correspondence with the defined shape, particularly according to one of the claims 10 to 12, the depth of the hollow being continuously measured, particularly according to one of the claims 7 to 9,

    characterised in that

    the measured values are continuously stored together with the respective coordinates or in memory locations corresponding to the respective coordinates and used for a later control of the laser processing device.

14. Method according to claim 13, characterised in that a stored measured value is used when the laser is close to the position corresponding to the measured value within the same layer and/or when the laser is close to or at the position corresponding to the measured value in a lower layer.

15. Method according to claim 13 of 14, characterised in that a measured value is used for the immediate or a later adjustment of interaction parameters of the laser beam.

16. Method according to claim 15, characterised in that the laser amplitude and/or the pulse exaggeration and/or the scanning ratio of a pulsed laser are adjusted.

17. Method according to one of the claims 13 to 16, characterised in that the stored measured values are used for the removal of a partial layer.

18. Apparatus for a depth measurement in a hollow (10), particularly for carrying out the method according to one of the claims 7 to 9, the hollow being generated by a laser processing device (12 - 18) guiding the laser light across the surface of the workpiece within a working area predetermined by the device with the aid of a laser beam guide, comprising

a depth sensor (70, 71) using light emitted from the working position for the depth measurement and generating a measured value,

characterised by

a calibrating device (72 - 74) suitable for measuring a preferably plane calibration surface and comprising a memory (73) for storing correction values depending on differences between measured values and known values together with the respective coordinates or in memory locations corresponding to the respective coordinates, and

a correction device (74, 75) correcting the measured value depending on the position of the location and with reference to the correction values stored in the memory (74).

19. Apparatus according to claim 18, characterised in that the correction is carried out by addition and/or multiplication.

20. Apparatus according to claim 18 or 19, characterised in that a correction is effected depending on the depth of the hollow.

21. Apparatus for producing a hollow (10) of defined shape in a workpiece (11), particularly for carrying out the method according to one of the claims 10 to 12, comprising

a laser processing device (12 - 18) for a layer-wise removal of the material of the workpiece (11) in horizontal layers (S; x, y) in correspondence with the defined shape, and

a measuring device (70 - 73), particularly according to one of the claims 18 to 20, continuously measuring the depth (z) of the hollow,

characterised by

a control unit (81) determining the boundaries (x_g, y_g) in the horizontal direction for the substance removal in a following layer (S_{i+1}) from the shape definition and depending on the depth (z) of the hollow.

22. Apparatus according to claim 21, characterised in that the control unit comprises a determining means (82) for determining the thickness (Δz) of a removed layer (S_i) from measured hollow depths, the control unit (81) also determining the boundaries (x_g, y_g) in the horizontal direction for the substance removal in a following layer (S_{i+1}) from the shape definition and depending on the determined layer thickness (Δz).

23. Apparatus according to claim 21 or 22, characterised by a memory (83) for storing the shape definition of the hollow (10).

24. Apparatus particularly according to one of the claims 21 to 23 for producing a hollow (10) of defined shape in a workpiece (11), particularly for carrying out the method according to one of the claims 13 to 17, comprising

a laser processing device (12 - 18) for the layer-wise removal of the material of the workpiece (11) in correspondence with the defined shape, and

a measuring device, particularly according to one of the claims 18 to 20, continuously measuring the hollow depth (z),

characterised by

a memory device (91) continuously storing the measured values together with the respective coordinates or in memory locations corresponding to the respective coordinates, and

a control unit (63, 92, 93) controlling the laser processing device (12 - 18) depending on the stored measured values.

25. Apparatus according to claim 24, characterised in that the control unit uses a stored measured value when the laser is positioned close to the position corresponding to the measured value within the same layer and/or when the laser is positioned close to or at the position corresponding to the measured value in a lower layer.

26. Apparatus according to claim 24 or 25, characterised in that the control unit uses a measured value for an immediate or later adjustment of interaction parameters of the laser beam.

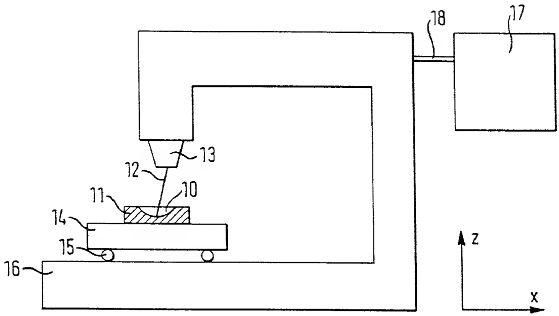
ABSTRACT OF THE INVENTION

DEPTH MEASUREMENT AND DEPTH CONTROL OR AUTOMATIC DEPTH CONTROL FOR A HOLLOW TO BE PRODUCED BY A LASER PROCESSING DEVICE

According to a method for a depth measurement the depths of measuring points on a calibration surface are measured and correction values depending on differences between the measured values and known values are used and stored for a later correction. According to a method for the layer-wise production of a hollow the horizontal boundaries (x_g, y_g) for the removal of a layer (S_{i+1}) depending on the hollow depth (z) were determined from the shape definition of the hollow. The measured values can be continuously stored and used for a later control of the laser processing device.

(Fig. 1)

FIG. 1



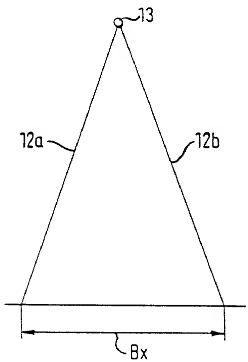


FIG. 2

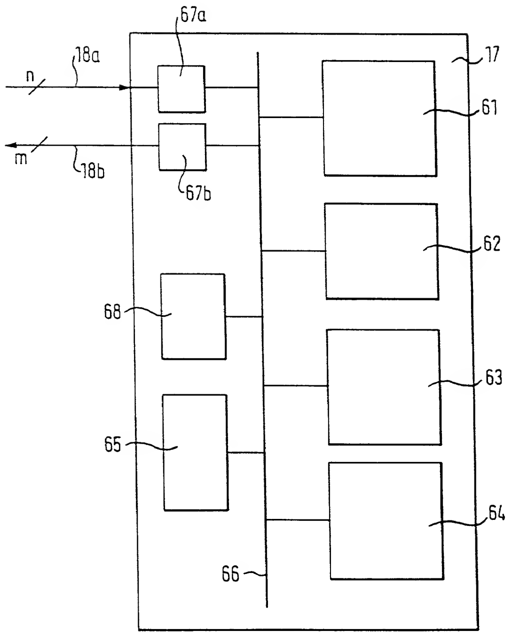


FIG. 3

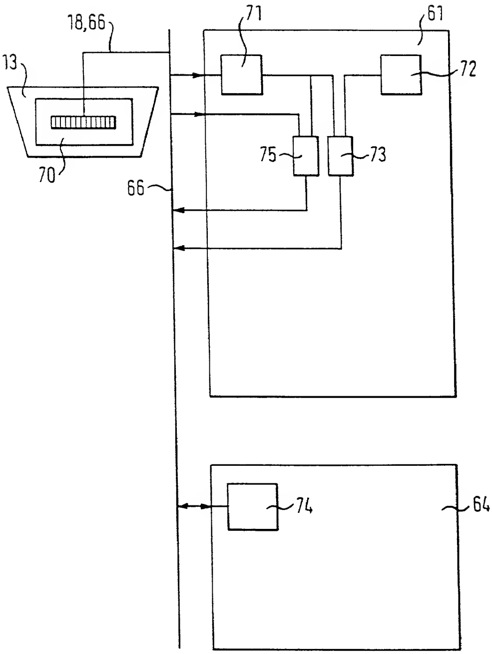


FIG. 4

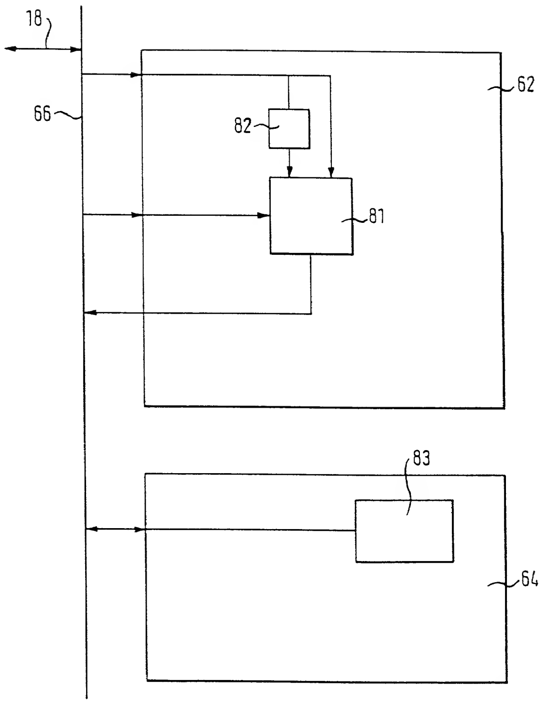


FIG. 5

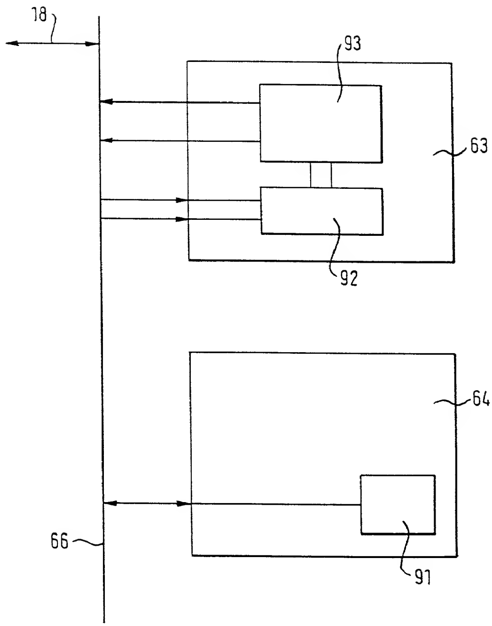


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FIG. 6

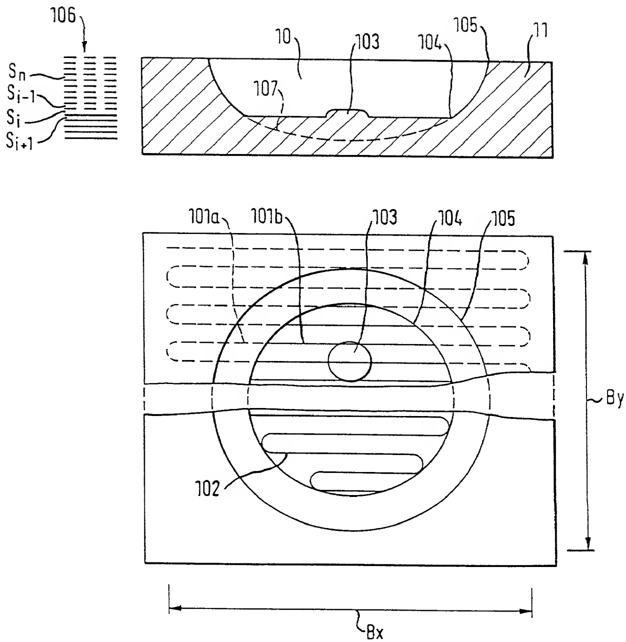
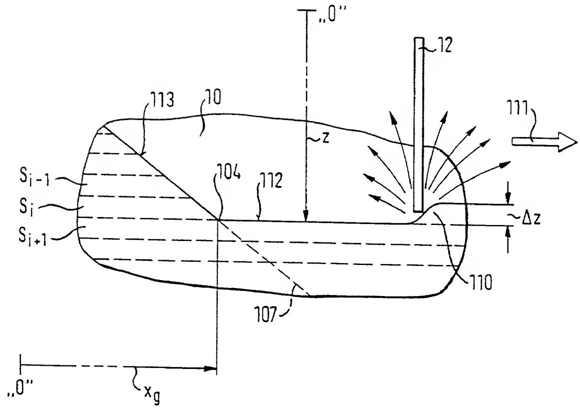


FIG. 7



Express Mail No. EL725699477US Attorney Docket No. BEET-03

DECLARATION, POWER OF ATTORNEY, AND PETITION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and joint inventor, of the subject matter which is claimed and for which a patent is sought on the invention entitled:

DEPTH MEASUREMENT AND DEPTH CONTROL OR AUTOMATIC DEPTH CONTROL FOR A HOLLOW TO BE PRODUCED BY A LASER PROCESSING DEVICE

the specification of which (check one below):

(✔) is attached hereto.

( ) was filed on _ as Application Serial No. ________________ or Express Mail No.______________, and was amended on ____ (if applicable).

( ) was filed on ___ as PCT International Application No. ___ , and as amended under PCT Article 19 on ___ (if any).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, §119of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s) Priority Claimed?

(Number)	(Country)	Day/Month/Year Filed	Priority Claimed?
PCT/EP98/06225		9/30/98	(X) Yes ( ) No
			( ) Yes ( ) No
			( ) Yes ( ) No

I hereby claim the benefit under Title 35, United States Code, §120and/or §119(e) of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112,I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations §1.56, whichbecame available between the filing date of the prior application and the national or PCT international filing date of this application.

(Serial No.)	(Filing Date)	(Status: Patented, Pending, or Abandoned)

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Wherefore I pray that Letters Patent be granted to me for the invention or discovery described and claimed in the foregoing specification and claims, and I hereby subscribe my name to the foregoing specification and claims, declaration, power of attorney, and this petition.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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